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ACID PRECIPITATION IN ONTARIO STUDY

LINEAR PROGRAMMING SCREENING MODEL
FOR
DEVELOPMENT AND EVALUATION OF
ACID RAIN ABATEMENT STRATEGIES

SEPTEMBER 1983

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LINEAR PROGRAMMING SCREENING MODEL FOR DEVELOPMENT AND EVALUATION OF ACID RAIN ABATEMENT STRATEGIES

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September 1983
(Reprinted June, 1985)

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1.0 INTRODUCTION

The Ontario Ministry of the Environment has dedicated considerable time and resources to the study of the phenomenon commonly known as "Acid Rain". From this effort, impressive progress has been made in understanding the causes, effects and technologies available for reducing the emissions responsible for acid rain.

This knowledge can provide the basis for determining acidic deposition objectives to protect the environment. It does not, however, solve the policy maker's problem of determining how much emission reduction, overall and by individual sources, must be undertaken to achieve specified deposition targets in receptor areas. Formulating and evaluating strategies for reducing acidic deposition is an arduous task, particularly because of the numerous approaches and criteria that may potentially be used to allocate emission reductions among SO_2 emitters. For this reason, abatement strategy development is critically in need of a procedure to identify and "screen out" what are considered to be the most socially-desirable options. To this end, an analytical procedure was developed which reduces the number of possible policy options by identifying those strategies which are both efficient in terms of minimizing control costs and effective in terms of achieving the desired deposition objectives. Because the role of the procedure is to identify the most viable options, the model is referred to as the Screening Model.

The purpose of this report is to provide a summary of the Screening Model. What follows is an overview; it is not intended that the overview be comprehensive in itself. Instead, a less formal discussion aimed at the general reader interested in the underlying logic of the approach is presented. For more detailed information describing the structure of the model, the reader is referred to the forthcoming appendices to this report (under separate cover) entitled, Appendix I "Mathematical Model Documentation of Datagen", Appendix II "Development of SO_2 Emission Control Costs", and Appendix III "Canadian Source Inventory". These reports will be available from: Policy and Planning Branch, 135 St. Clair Avenue West, Toronto.

2.0 COST-EFFECTIVE APPROACH TO ABATEMENT OF ACIDIC DEPOSITION

Traditional approaches to air pollution control were designed mainly to address local problems associated with high pollution concentrations near the pollution source. Achieving compliance with ambient standards involved either the source reducing its emissions or diluting the pollution concentration through construction of taller smokestacks.

Unfortunately, existing air quality control programs are poorly suited to abatement of the acid rain problem. The focal point associated with acid rain damage is the total deposition loading over a region, as opposed to pollution concentrations. Moreover, acid pollution travels over great distances, often crossing jurisdictional boundaries, with the result that deposition at any location is the result of emission contributions from many sources. As a result of these distinctive characteristics, novel approaches for controlling acid pollution must be developed. Three general approaches have been proposed:

1) emissions-driven;
2) deposition - targeted; and,
3) cost-effective or least-cost targeted.

An emissions-driven strategy refers to any program specifying emission reductions to be achieved by specific sources. Programs that would impose universal 50% emission reductions or alternatively reductions weighted by a sources' contribution to total provincial emissions, are examples of emission-driven abatement strategies. The major deficiency of such strategies is that source reductions are advocated independently of both their contribution to acidic deposition and their cost.

The emissions-driven position, then, explicitly ignores fundamental aspects of acid rain, namely, that pollutants are transported over long distances and that acid deposition at any location is the result of emissions from many sources at different locations.

Alternatively, a deposition-targeted approach considers the set of sources that must be controlled to achieve specified deposition levels at receptor locations. To accomplish this more informed approach to decision-making requires an understanding of the linkage or relationship, between source emissions and the resultant acidic deposition in defined receptor areas. Such linkage information is available through use of Long-Range Transport of Air Pollutant (LRTAP) Models that simulate the complex physical and chemical processes which control pollution transport. Using LRTAP models, the contribution of any given emission source to the total acidic deposition received at any given receptor area can be estimated.

From a policy context this capability is important on two accounts. First, it can be used to identify the acidic deposition consequences for receptor areas of implementing an emissions-driven strategy. Secondly, given a desired level of deposition for each receptor, the emission reductions necessary to achieve those objectives can be determined.

Despite its improvements over the emissions-driven approach, the deposition-targeted method is still inadequate. Two problems are noteworthy. The set of emission source controls required to achieve specified deposition levels may not be unique. That is, a number of source-reduction combinations may yield the same deposition levels at receptor areas. None of these combinations may possess any inherently distinguishing feature from which a policy decision can be made.

A further objection is that costs to control emissions are not considered. A regulatory agency which ignores control costs in this manner runs the risk of adopting policies which are not cost-effective.

To redress these concerns, a methodology was developed which synthesizes cost of abatement and the source/receptor linkage information. This new orientation influences policy direction by providing answers to the questions:

1) What effect does an abatement program have on deposition at receptor areas?

2) What effect does the choice of strategy have on the costs of controlling emissions?

Answers to these questions provide a basis for comparing the relative efficiency and effectiveness of abatement policies. As well, the decision-makers problem of having to select from a number of equally effective abatement options is eased by applying the criterion of least-cost. The decision problem thus becomes one of searching for a set of emission reductions that will minimize abatement costs subject to the condition that the desired deposition levels are met. Under this least-cost-targeted approach, sources with the lowest marginal costs per unit reduction of deposition at critical receptor areas would undertake the greatest degree of control.

The intent of this section was to briefly outline the rationale and advantages of adopting a least-cost targeted philosophy in establishing a policy for controlling acidic deposition. In the following section, the emission source inventory, source/receptor relationships and control costs which are input to the analytical model are discussed.

3.0 OVERVIEW OF MODEL STRUCTURE

Models are simplified characterizations of real systems that generally rely on mathematical expressions to describe and simulate processes and predict system behaviour. In the present model, three features help to capture the linkage between source emissions and receptor area deposition rates while enabling an analysis of cost-effective abatement strategies:

i) Major sources and sensitive receptor areas (receptors) are individually identified and described;

ii) Information from an atmospheric long-range transport model is used to link source emissions to receptor deposition levels; and,

iii) Relying on the source-receptor linkage, a decision analysis technique called linear programming is used to identify levels of emission control at each source that will meet specified deposition targets at receptors while keeping emission control costs as low as possible.

Within the modelled area, discrete point sources and diffuse sources generate SO_2 emissions that, to a greater or lesser extent, contribute to the deposition of sulphates at each of the receptors. Long-range transport models* are used to simulate the physical and chemical processes that cause this contribution. Information from these long-range transport models, in the form of transfer coefficients**, is used in the Screening Model to link source emissions to receptor deposition levels. In effect, every source contributes to the deposition at each receptor, with the amount being explicitly accounted for in the Screening Model. This linkage is schematically depicted in Figure 1.

The Screening Model is not a long-range transport model itself but, instead relies on information developed from such models. Rather, the Screening Model is designed expressly to analyze acid deposition management decisions. In this analysis, it relies on linear programming, a mathematical procedure that is used to "sort through" a large set of possible management options in order to identify one which is optimal from the point of view of specified criteria. These criteria are formulated either as constraints that must be met or as an objective to be achieved. For the acid deposition

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* e.g. Ontario Ministry of the Environment, "Documentation of the Ontario Ministry of the Environment Statistical LRT Model OME-LRT", Work Group 2, Report 2-8, prepared for the Atmospheric Modelling Subgroup, March 31, 1981.

** See Section 4.4 for a discussion of transfer coefficients.

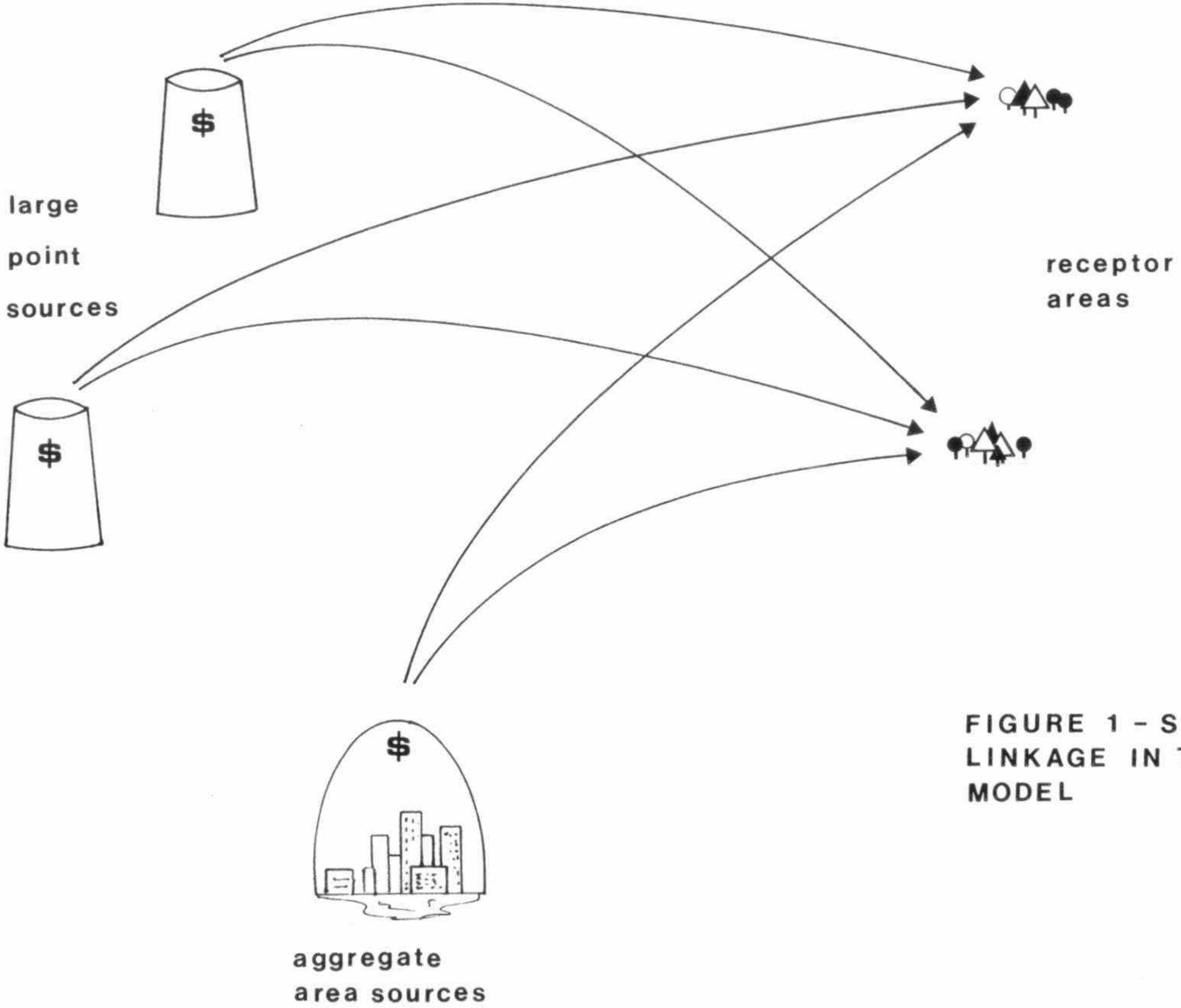

FIGURE 1 - SOURCE/RECEPTOR LINKAGE IN THE SCREENING MODEL

Screening Model, minimization of emission control costs can be formulated as the modelling objective. This objective is achieved subject to constraints requiring that receptor deposition levels be at, or below, maximum allowable limits.

The emission control levels at each source are adjusted during model operation in order to satisfy both the objective and the contraints. They are the planning parameters about which decisions are being made within the model and thus are called decision variables.

It is possible to include additional decision criteria in the acid deposition Screening Model such as might relate to policy or political considerations.

4.0 DATA INPUT REQUIREMENTS

4.1 POLLUTANT SOURCES

The data requirements for the model are substantial. The starting point for assembling the requisite data inputs is a network of sources and receptors. For the current model applications this network encompasses areas of Canada and the U.S. east of the Rocky Mountains. Emission sources within this area are introduced into the Screening Model either as large point sources or as aggregate "area" sources.

A total of 235 large point sources have currently been selected on the basis that their 1980 emissions exceeded 19,000 tonnes per year of SO_2. Included in this group are Canadian and American power plants and non-power plants as follows:

	Power Plants	Non-Power Plants	Total
Canadian	9	7	16
American	178	41	219
Total	187	48	235

Estimated emissions for these large sources are:

	Total Emissions for Sector (kilotonnes/yr)	Percentage (%) of Country-wide Total*
Large Power Plants in Canada	542.6	11.8%
Large Non-Power Plants in Canada	2169.0	47.3%
Canadian Totals	4582.7	59.1%
Large Power Plants in U.S.	12721.7	60.7%
Large Non-Power Plants in U.S.	1606.1	7.7%
U.S. Totals	20954.8	68.4%

* Estimated for modelled areas in the respective country, i.e. for regions east of the Rocky Mountains.

Overall, these large sources represent approximately 67% of total man-made emissions of SO_2 that originated within the modelling area in 1980. Detailed emission control data and associated cost information are currently given only for these large sources in the Screening Model. They are therefore the controllable sources.

The remaining emission sources, consisting of a few large point sources, point sources emitting less than 19,000 tonnes per year, and diffuse sources, have been aggregated by state and province into area sources. There are 92 such area sources, including:

	Power Plants	Non-Power Plants	Total Number
Canadian	9	9	18
American	32	42	74
Total Number	41	51	92

Area source emissions are currently fixed in that no control technologies are applied to them in the Screening Model. However, emission controls for area sources are being considered. They may be introduced to the model by assuming, for example, the desulfurization of heating oil at refineries and the resulting combustion of lower sulfur fuels at points throughout the area source.

In addition to the emissions that originate from point and area sources, there are emissions both from natural sources and from man-made sources that lie outside of the boundaries of the study area. These sources are accounted for in the Screening Model by means of a "background deposition level" at each receptor. Currently, the background deposition levels have been set for all receptors at 2 kilograms per hectare annually of wet-deposition sulfur, (6 kg SO_4/Ha-yr) but these values are individually assigned for the various receptors and therefore can be varied if necessary.

4.2 ABATEMENT TECHNOLOGIES

For each of the 235 large emission sources in the screening model, SO_2 emission levels are specified along with estimated removal efficiencies and costs for new emission control techniques.

Emission data are based on 1980 estimates of emissions prepared by the Ontario Ministry of the Environment. These estimates reflect production activity levels for that year and the impact of control technologies that were in place at the time.

Fuel sulfur content controls such as coal cleaning are handled at the plant level. For flue-gas and off-gas desulfurization techniques, removal efficiencies and control costs are determined for individual boiler and production lines that are found at each plant. Thus, a power plant with four coal fired boilers could have limestone scrubbers assigned to each boiler separately as well as coal cleaning for all boilers. The alternative emission control options at that plant would then consist of coal cleaning with or without the four scrubbers taken separately or in combination. Maximum reductions would occur with all four scrubbers installed plus coal cleaning.

A certain amount of site-specific information was required to enable the analysis of SO_2 emission controls. For power plants this includes:

Item	Units
Annual Capacity Factor	%
Fuel - Type	-
- Consumption Level	weight
- Sulfur Content	% by weight
- Heat Content	Btu/lb
Boilers - Number	-
- Capacities	MW
SO_2 emission	Tonnes/yr
Existing SO_2 Removal by Boiler	%

For each non-power plant emission source, information requirements were:

Item	Units
Operating Schedule	hours, days, weeks
Number of Emission Points	-
Flue Gas Volume	cubic feet/min
Flue Gas Temperature	°F
Flue Gas SO_2 Content	% Volume
Production Process Type	-
Existing SO_2 Removal by Point	%

Control technologies considered in the analysis of power plants include:

i) physical coal cleaning (25% removal of coal sulfur);

ii) coal substitution down to 1.4% sulfur; and,

iii) flue gas desulfurization using limestone scrubbing (up to 90% removal of SO_2).

For the industrial or non-power plant sources, a variety of technologies are considered, depending on the industry and production processes at each source:

Process Name	Removal	Application
Limestone FGD	90%	- weak gas streams from boilers and various production processes
Acid Plant	95%	- strong gas streams from non-ferrous smelters

Wellman Lord FGD	90%	- sulfuric acid plant off-gases
Vacuum Carbonate Process with Claus Sulfur Recovery	93%	- cooking oven off-gas in the iron and steel industry
Petroleum Refinery Controls	Up to 75%	- petroleum refineries

For each of the control techniques identified above, cost expressions were obtained that related variables such as fuel sulfur concentrations and flue gas flow rates to treatment cost. These expressions are based on published cost estimates for the various technologies. Separate expressions are used for capital costs and annual operating and maintenance costs. (See Appendix 2 for a detailed discussion of emission control costing.)

The emission control cost expressions are in effect generic cost curves which fail to account for site specific conditions. They have been applied to all sources for which site specific cost estimates were not available; namely all American sources and Canadian power plants outside of Ontario. For the remaining sources, more detailed cost estimates were obtained for SO_2 emission controls.

Total costs for a technology applied at an emission point in a plant were calculated as the sum of capital costs and the present value of annual operating and maintenance costs incurred over a 20 year period. Capital costs represent the value at the end of the construction phase of expenditures incurred to put a control technology in place.

The present value of future operating and maintenance expenditures is determined by adjusting future expenditures by an interest rate factor. This interest rate adjustment converts future expenditures into equivalent present day values thus accounting for the time value of money*.

The present value of future expenditures measures the size of an annuity fund that would have to be created at the beginning of the planning period in order to just cover forecast future costs over the full planning horizon. The total cost therefore measures the amount of money that would have to be provided in year one in order to cover construction costs incurred up to that point in time and to cover all future operating and maintenance costs.

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* For an interest rate of 10%, the interest rate factor for a cost incurred in year "n" is:
$1/(1+.10)^n$
The present value of that cost is: P.V. = (cost in year n)/ $(1 + .10)^n$

Project costs in the Screening Model do not consider the possibility of production cost savings or by-product revenues. For the non-power plant sources these could at times be significant and an upward bias in certain costs could therefore occur. On the other hand, the generic cost estimates used here will be low if unaccounted for factors act to increase costs.

The primary analysis of removal efficiencies and costs associated with discrete emission points at a source provided a table of possible control options for that source as evidenced by the individual points plotted in Figure 2. From these control options taken individually and in combination, those which were most cost-effective, are identified as potential control measures to be input into the screening model. Before being input to the screening model however, the plot of individual control options at a source was converted into a continuous or smooth removal-cost relationship. This is accomplished by joining key least-cost points with continuous linear segments as shown in Figure 2.

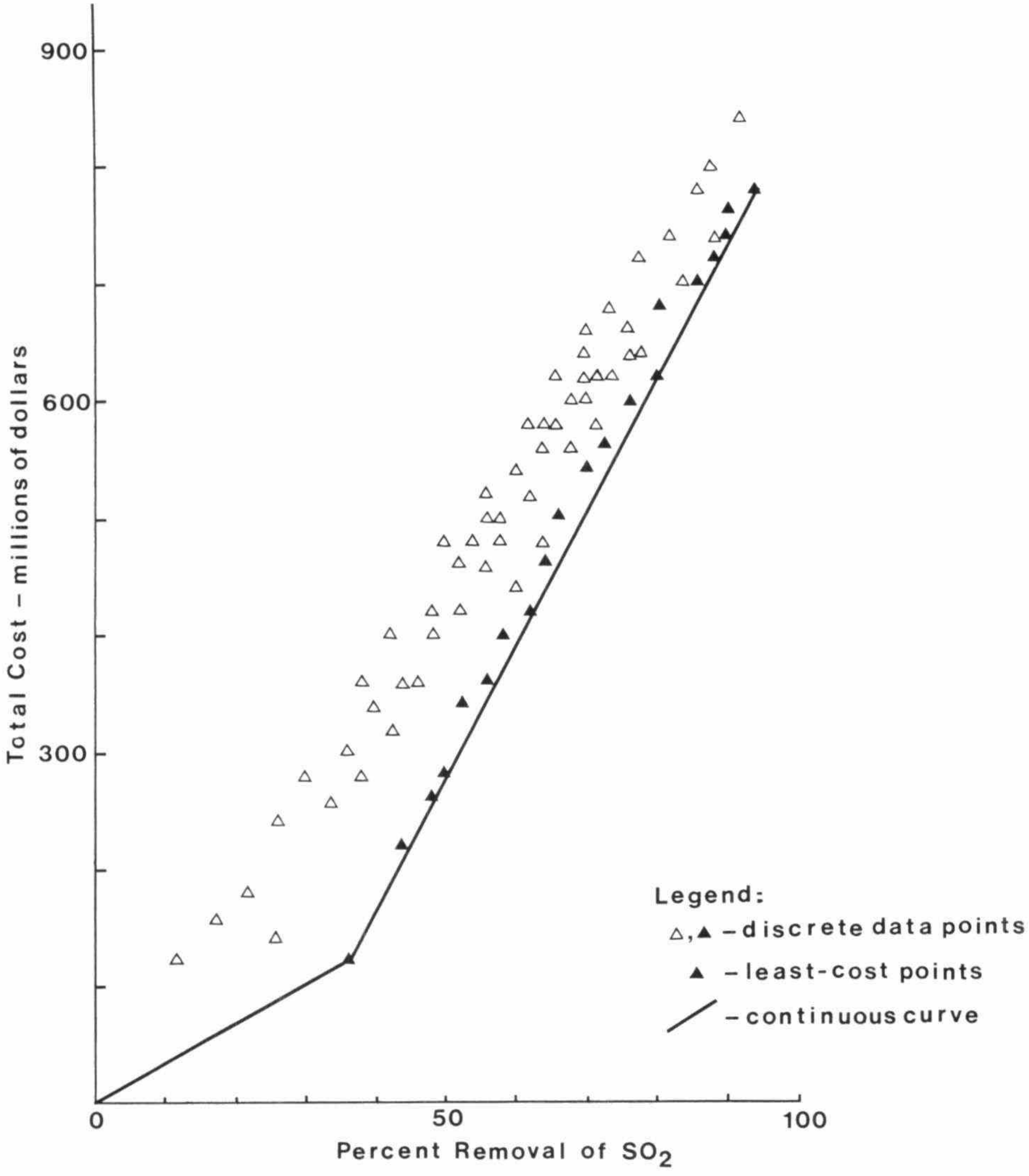


FIGURE 2 - SO_2 REMOVAL/COST RELATIONSHIP

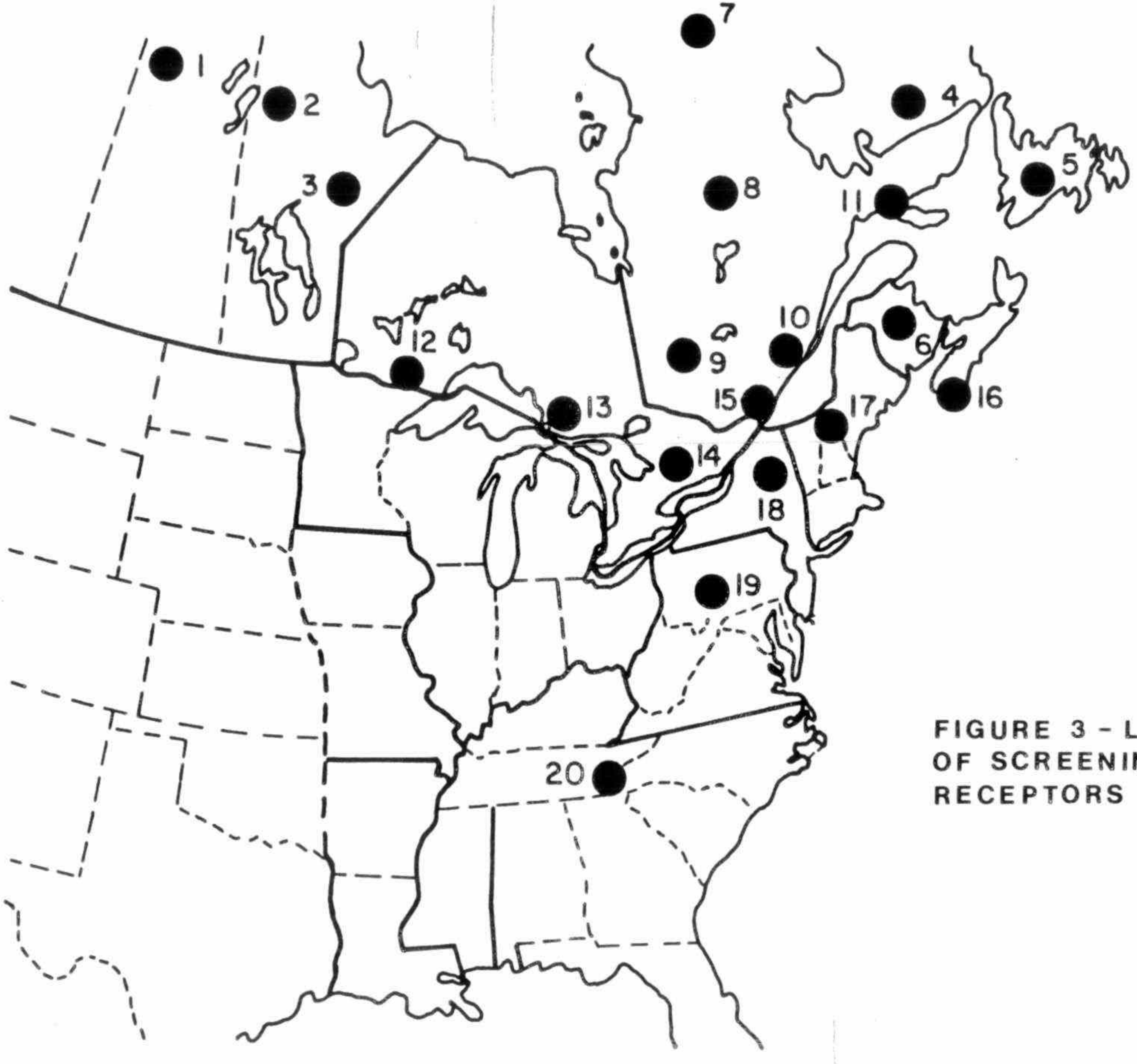


FIGURE 3 - LOCATION OF SCREENING MODEL RECEPTORS

The Screening Model uses the continuous removal-cost relationships in analyzing abatement strategies. In so doing, it is free to select any combination of cost and removal level found along the linear segments of the curve. Output from the Screeing Model is matched against the set of discrete removal-cost points to identify a specific control option that corresponds most closely to the point on the continuous relationship that was chosen by the model. (For further explanation, see Appendix I).

Note that the concept of cost effectiveness is applied in deriving removal-cost relationships for each source as well as in the identification of an overall abatement strategy. At both levels of analysis, least-cost options are selected to control SO_2 emissions.

4.3 RECEPTOR AREAS AND DEPOSITION TARGETS

Twenty locations are currently employed within the model to assess deposition rates in areas that are most susceptible to damage from acid deposition (see Figure 3). The model can be expanded to include additional receptors as needed.

The deposition criteria at these receptors are expressed in terms of maximum allowable receptor-deposition rates. These rates, which represent wet deposition only, are imposed as constraints upon management strategies generated by the Model.

Currently, a single maximum allowable deposition rate is set for all of the twenty receptors, one particularly important level being 20 kg (SO_4)/ha-yr (or 6.7 kg S/ha-yr). This deposition is the sum of depositions attributed to: (1) each individual emission source, (2) each area source, and (3) the deposition caused by natural and unaccounted anthropogenic sources. Analyses to date indicate that a level of 20 kg $(SO_4$/ha-yr) is only attainable when emission controls are applied at a large number of both Canadian and American emission sources. Higher and lower target levels have been tested to check the response of emission control requirements to this parameter.

One can also assign different target levels for deposition at each receptor if, for instance, assimilative capacities vary from region to region.

4.4 SOURCE/RECEPTOR POLLUTANT TRANSPORT

For all work to date, the statistical model of the Ontario Ministry of the Environment has been used to produce transfer coefficients for the Screening Model. A transfer coefficient is needed for each source/receptor pair. As a result, 6,540 transfer coefficients are input into the model (i.e. 20 receptors x [235 point sources + 92 area sources] = 6,540).

Transfer coefficients represent unit response rates that measure the kilograms of sulfur deposited annually per hectare at the receptor that can be attributed to an annual emission of one tonne of SO_2 at a source.

The deposition at a receptor corresponding to the base case emission from a particular source is estimated as:

(base case emission in tonnes SO_2/year) x
(transfer coefficient for that source-receptor pair)
= wet deposition in kg S/ha-yr.

The total wet deposition at a receptor is the sum of depositions from controllable sources plus deposition associated with area source emissions and background sources.

5 0 MODEL OPERATION AND OUTPUT

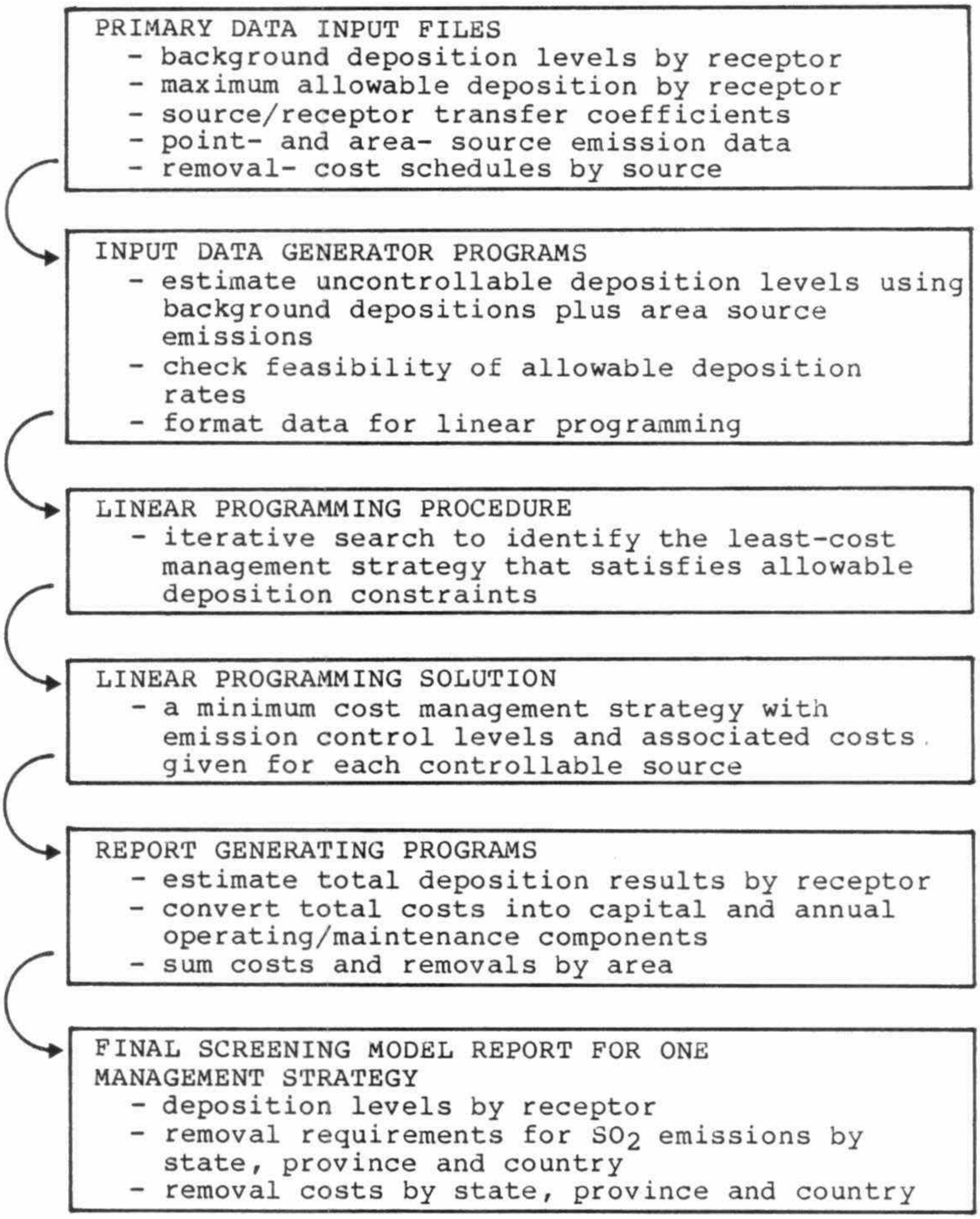
5.1 INTRODUCTION

The core of the Screening Model is the linear programming procedure. Computer programs were required to both prepare input data files to the linear programming procedure and to transform resulting output into a legible report. These two computer programming tasks entailed the development of a hierarchy of computer programs and data sets that together comprise the acid deposition Screening Model. This hierarchy is illustrated and briefly described in Figure 4.

The primary data input files indicated in Figure 4 are the result of preparatory work in reviewing information sources and assembling or estimating data inputs. These files are processed by the input data generator programs to produce the input data sets for the linear programming procedure.

5.2 LINEAR PROGRAMMING

The linear programming decision variables are defined as the SO_2 removal efficiencies



PRIMARY DATA INPUT FILES
- background deposition levels by receptor
- maximum allowable deposition by receptor
- source/receptor transfer coefficients
- point- and area- source emission data
- removal- cost schedules by source

INPUT DATA GENERATOR PROGRAMS
- estimate uncontrollable deposition levels using background depositions plus area source emissions
- check feasibility of allowable deposition rates
- format data for linear programming

LINEAR PROGRAMMING PROCEDURE
- iterative search to identify the least-cost management strategy that satisfies allowable deposition constraints

LINEAR PROGRAMMING SOLUTION
- a minimum cost management strategy with emission control levels and associated costs given for each controllable source

REPORT GENERATING PROGRAMS
- estimate total deposition results by receptor
- convert total costs into capital and annual operating/maintenance components
- sum costs and removals by area

FINAL SCREENING MODEL REPORT FOR ONE MANAGEMENT STRATEGY
- deposition levels by receptor
- removal requirements for SO_2 emissions by state, province and country
- removal costs by state, province and country

FIGURE 4 - SCREENING MODEL STRUCTURE AND OPERATION

at each controllable source (see Section 4.1 and 4.2). These removal efficiencies, expressed as a fraction between zero and one, enter into the equation describing the Model's least-cost objective where total removal costs are estimated. The coefficients in this equation measure removal costs. The removal efficiency variable multiplied times the cost coefficient will give the total emission control cost corresponding to a given level of SO_2 removal at a source.

Total abatement costs are measured as the sum of removal costs incurred at every controllable source. This value is minimized using an iterative mathematical routine whereby all feasible combinations of control options selected aross the controllable sources are considered. There are a very large number of such combinations; however the iterative search using linear programming is relatively quick and efficient as a result of mathematical properties of the input data sets.

In searching for the minimum value of the objective function, the linear programming routine progresses through two stages. First, costs are ignored and the Model merely adjusts the emission control removal levels until constraints such as those describing allowable deposition rates are all satisfied.

For example, the linear programming routine will increase the emission control removal efficiencies until total deposition rates at each receptor are no greater than the allowable rates. When this is achieved, the corresponding set of values for the emission control decision variables is called a "feasible solution".

If the required reduction in deposition at any receptor exceeds the maximum attainable reduction that can be achieved then no feasible solution exists. In other words, the target deposition level cannot be achieved using the control technologies that underlie the removal-cost relationships in the Model.

If a feasible solution can be found, the next stage in linear programming commences. This entails an iterative procedure to identify where, and by how much, emission control removal levels can be relaxed without violating deposition constraints. In this step, all of the many source/receptor interactions must be considered simultaneously.

Usually, there is only one least-cost feasible solution for any particular set of input data; this is called the "optimal solution".

5.3 MODEL OUTPUT

The optimal solution provides a data set prescribing emission control levels and associated costs for each of the 235 controllable sources. This data set is interpreted by report generating programs that produce final Model outputs.

The primary Model outputs include the following:

- removal efficiency (in percent) at individual controllable sources;
- abatement costs for control at each source (capital, annual operating and maintenance, and present value of total costs in millions of U.S. 1981 dollars);
- final emission levels at each source (tonnes SO_2 per year); and,
- deposition levels at each receptor arising after the individual source abatement efforts are in place (kg S per ha-yr). Deposition levels will be at, or below, the target level.

For reporting purposes, several levels of output are available (see Figure 5). Detailed source data are aggregated by state, province and country to reduce the volume of output. Power plant and industrial data are reported separately. Deposition rate data for each receptor are also displayed. Examples of Model outputs are provided in Section 6.2.

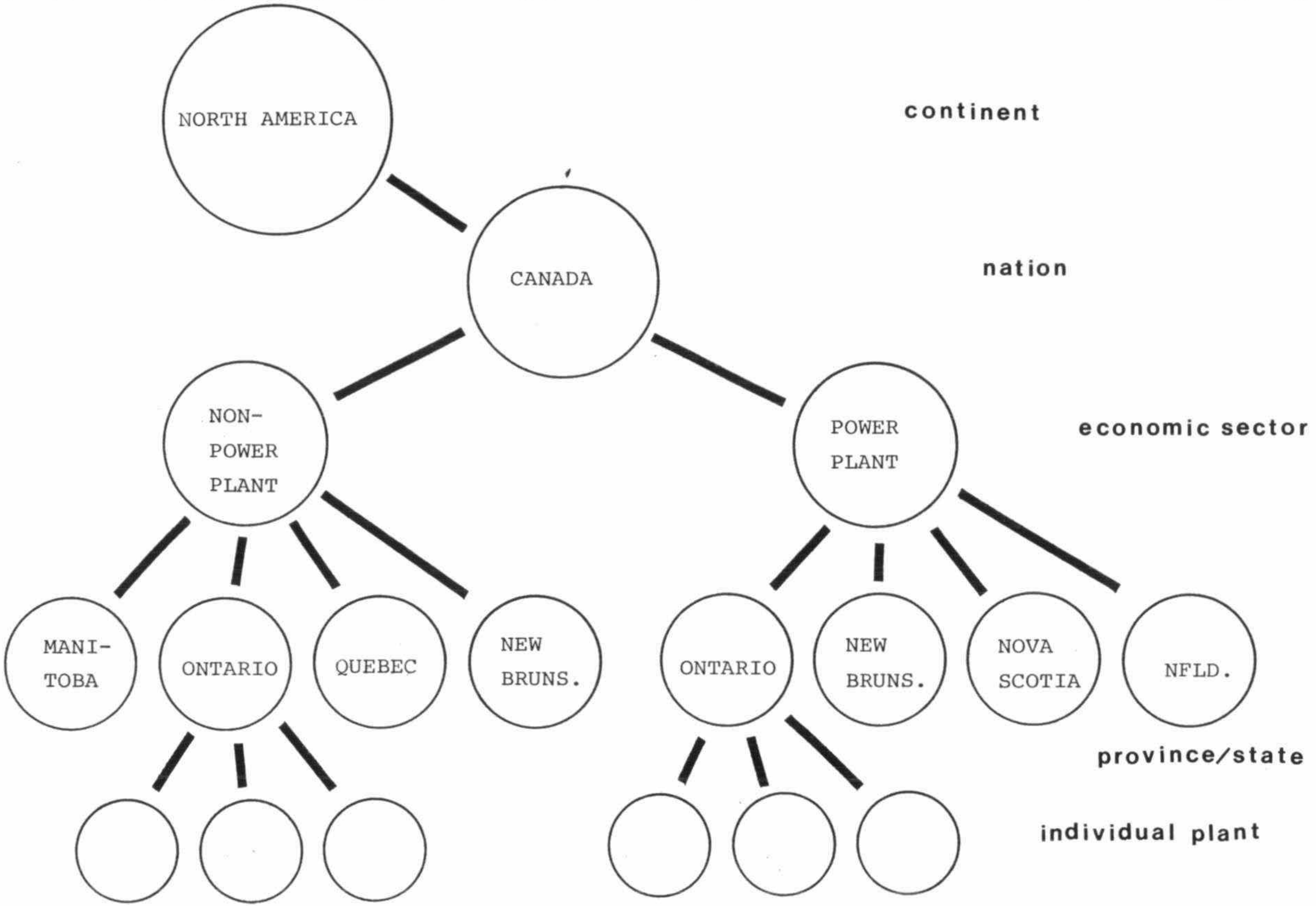


FIGURE 5 - LEVELS OF AGGREGATION FOR SCREENING MODEL OUTPUTS

6.0 MODEL APPLICATION FOR STRATEGY ANALYSIS

6.1 APPROACH TO THE ANALYSIS OF STRATEGIES

The output from one application of the Screening Model provides a complete set of required abatement actions at each of the controllable emission sources, along with associated costs, and resulting deposition rates for a specified set of constraining conditions. This output comprises a data set for evaluating a single strategic option.

Although there is only one "optimal solution" for any given set of input data, the Screening Model is not meant to be used to identify the single most "optimal" management strategy. Even if such a strategy exists, it is unlikely to be discovered by any computer program in light of the data deficiencies and uncertainties that persist. Rather, the Screening Model functions to identify a small set of interesting or promising management strategies. This is achieved by successive applications of the Screening Model to input data sets that vary according to modifications in the underlying assumptions about the decision criteria or the behaviour of the acidic deposition system.

For example, deposition targets may be varied across receptors. This could be done to reflect varying assimilative capacities across receptors or to minimize the influence of certain receptors at which the deposition targets prove particularly difficult to meet. Alternative estimates of emission control costs, base case emissions or transfer coefficients may also be tested.

Upper and lower bounds are specified for emission controls at each source. While these are typically used to reflect technological constraints on removal efficiency, they can be modified for instance to fix emissions for a source at existing levels (no additional control allowed) or to force a source into the management strategy (lower bound raised to prevent zero removal). In this way, complete sets of sources, designated by type or by political jurisdiction can be manipulated externally in order to explore different policy options.

One can also use modifications in the input data set to look at the economic costs of imposing equity rules on the abatement efforts undertaken across political jurisdictions or across specified sectors of industry. One such rule would call for equal percentage reductions across nations.

By utilizing one or more of a wide array of possible constraints, the acid deposition Screening Model can be a very flexible tool in examining alternative management strategies.

6.2 EXAMPLE APPLICATIONS

Two model applications are described in the following pages. They are included only for purposes of explaining the type of results generated by the Model and are preliminary in nature since certain model inputs are still being updated. Both applications utilize the same "base case" structure or set of constraints; consisting only of the requirement that the maximum deposition rates are not exceeded at any of the twenty sensitive receptors. There are no "special" or additional constraints such as restrictions on removal levels within a political jurisdiction. The applications differ only in the maximum allowable deposition rate. Application number 1 utilizes a target of 25 kg SO_4(wet)/ha-yr. The target for application number 2 is 20 kg SO_4(wet)/ha-yr.

These two scenarios show how controllable source SO_2 removal levels and accompanying costs increase as the maximum allowable deposition target becomes more stringent (i.e. lower).

Before applying the Model, the maximum allowable deposition targets were modified to account for receptor-specific predicition errors inherent in the transfer coefficients obtained from the MOE Statistical Model. When compared to measured SO_4 deposition rates, the Statistical Model overpredicts deposition at some receptors while underpredicting it at others. These discrepencies can be expressed as "predicition factors" which are simply measured deposition rates divided by model-predicted deposition rates (deposition rates here being measured net of background deposition levels). The maximum allowable deposition rates used in the Model are the nominal values (25 and 20) divided by the receptor-specific prediction factors.

Deposition results for the two applications are provided in Table 1. In accord with the fundamentals of linear programming, the search for minimum cost ensures that at least one receptor will have a deposition rate equal to the maximum. For a base target level of 25 kg SO_4 (wet) /ha-yr, there are three such receptors: Muskoka, West Pennsylvannia and the Smokies. These receptors are termed "binding"

TABLE 1

DEPOSITION RESULTS FROM TWO EXAMPLE APPLICATIONS OF THE SCREENING MODEL

RECEPTOR NUMBER *	NAME	DEPOSITION VALUES (kg(SO_4)/ha-yr) Target Level = 25	Target Level = 20
1	Cree Lake, Sask.	3.0	2.9
2	Lynn Lake, Man.	7.7	7.0
3	Molson Lake, Man.	8.7	7.8
4	Goose Bay, Lab.	10.4	8.6
5	Red Indian Lake, Nfld.	15.5	13.7
6	Renous River, N.B.	17.3	14.3
7	Quebec North	3.1	3.0
8	Quebec Central	8.2	7.4
9	Quebec Southwest	20.6	16.3
10	Quebec South	24.9	19.9
11	Quebec Northeast	17.6	15.5
12	Boundary Waters	6.9	6.4
13	Algoma	14.3	11.0
14	Muskoka	25.0	18.3
15	Quebec City	24.8	20.0
16	Southern N.S.	17.3	13.8
17	New Hampshire	24.2	19.3
18	Adirondacks	24.0	17.7
19	West Penn.	25.0	16.2
20	Smokies	25.0	20.0

* See Figure 3 for location of receptors.

since the deposition targets here are the most difficult targets to satisfy. For this reason, the binding receptors largely govern the level of emission controls that are required.

When the deposition target is reduced to 20 kg SO_4(wet)/ha-yr, the binding receptors become Quebec City and the Smokies. This change is evidence of the complexity of the source/receptor linkage; emission abatement at one source to attain maximum allowed deposition at one receptor also has an impact on deposition rates at other receptors. The ability to accommodate this complex interaction in an efficient manner is a principal value of the Screening Model. Analytic approaches that lack this capability must fall back on trial-and-error procedures that are inefficient and unreliable.

The emission control levels and accompanying costs for the two applications are given in Table 2, for Canada and the United States. The aggregate removal levels and costs are higher for application 2 due to a more stringent deposition target in this application.

TABLE 2

EMISSION CONTROL LEVELS AND COSTS FOR TWO EXAMPLE APPLICATIONS OF THE SCREENING MODEL

	CANADA		UNITED STATES		
	Power Plants	Non-Power Plants	Power Plants	Non-Power Plants	Total
Emissions (10^3 Tonnes/yr)					
Existing (1980)	542.6	2169.0	12721.1	1606.1	17039.4
After Controls					
a) Dep. target = 25 kg SO_4	419.1	1384.1	10451.2	1603.4	13857.8
b) Dep. target = 20 kg SO_4	168.2	644.2	5407.5	997.4	7217.3
Emission Reductions (%)					
a) Dep. target = 25 kg SO_4	22.7	36.2	17.8	0.2	19
b) Dep. target = 20 kg SO_4	69.0	70.3	57.5	37.9	58
Costs (10^6 U.S. 1981 Dollars)					
a) Dep. target - 25 kg SO_4					
Capital	510.7	581.5	937.1	0.4	2029.7
O&M	62.8	50.6	357.6	0.1	471.1
Total	1230.5	1155.5	4990.2	1.6	7377.8
b) Dep. target = 20 kg SO_4					
Capital	1844.3	1025.6	10773.2	931.8	14574.9
O&M	198.5	132.4	1698.7	183.0	2212.6
Total	4094.0	2527.8	30293.5	3017.5	39932.8

3x

6x

5.5x

5.5x

5 x

The Screening Model output interpreter provides cost and removal results for three levels of aggregation; by country as shown in Table 2, by state and province, and individually by each controllable SO_2 source.

6.3 LIMITATIONS OF THE MODEL

As with any modelling exercise, limitations of the Screening Model arise from sources of uncertainty and error in the input data and from constraints on the scope and complexity of the model structure. These limitations must be kept in mind when Model results are used to analyse management strategies.

Invariably, data inputs are subject to a degree of uncertainty and error. For example, the base case emission levels from 1980 will clearly change as economic conditions shift and growth occurs. As scientific investigations proceed, data on transfer coefficients and deposition levels will improve. Such changes must have a bearing on our efforts to abate acid deposition. At this early stage in the strategy analysis, it is of paramount importance that sensitivity analysis be conducted in order to assess the potential importance of possible future changes in the Model input data.

All of the data inputs are subject to revision as better information becomes available. Indeed, the process of revision has already commenced, generic emission control costs for many Canadian sources have been replaced by more reliable site-specific emission control cost estimates. The degree of inference supported by Screening Model analysis must reflect the changing quality of the input data. While data inputs are in a very preliminary stage of refinement, Model outputs can be used to indicate relative rankings of management options and order of magnitudes of economic and environmental impacts. Absolute quantitative differences will take on more meaning only as the quality of the input data increases.

Much the same can be said of Model scope and structure. It is easy to envisage an improved model encompassing additional pollutants (NO_x for example), a more complete coverage of source and receptor areas, explicit measurements of receptor damages, and a more realistic scheduling of abatement activities. As it now stands however, many simplifying assumptions have been made. For instance, all prescribed control options are assumed to come on line in year one. Consequently, no inferences about priorization of sources and scheduling of abatement activities can be made on the basis of Screening Model results alone.

For the same reason, the financing and budgetory implications of abatement program costs cannot be assessed on the basis of Model results. At this stage, cost data in the model should only be used to evaluate the relative efficiency of alternative abatement strategies.

Limitations cited above do not invalidate the Screening Model. The Model provides a powerful and practical means of synthesizing large amounts of complex and disparate information describing acid deposition. Existing limitations serve to define how Model outputs should be interpreted and they will help direct efforts for future Model development.

7.0 SUMMARY AND FURTHER APPLICATIONS

The Screening Model described in this report is a computer model designed to assist in the discussion of strategies to abate acid deposition across eastern North America. In its operation it identifies a set of emission controls to be imposed at 235 major emission sources in Canada and the United States in order to achieve stipulated deposition targets at 20 receptors located in environmentally sensitive areas. The recommended controls represent the least cost manner of achieving the deposition targets. Only emissions of SO_2 and wet depositions of sulfur are accounted for. A set of emission controls obtained from one application of the model provides the data with which to evaluate a single abatement program or management strategy.

The principal merit of the model is that it provides, within a single model structure, the capability to simultaneously account for the complex interactions of multiple sources and receptors. Emission levels, control costs, pollutant transport and pollutant deposition at the receptors are all accounted for. The model therefore represents a significant advance in our efforts to develop an overview of the acid deposition problem.

Not only does the model foster an overview approach to the analysis of acid deposition, but it does so in a manner that is tailored to the needs of the decision maker. As a result of its reliance on linear programming, a tool for decision analysis, it can address salient questions that bear on the management decisions; questions such as:

- what can one political jurisdiction do on its own?

- how far can abatement from power plants alone (or any other sector of the economy) take us?

- how much more will it cost if everyone is forced to control emissions by say 50% rather than following the least cost option?

Finally, the model is flexible. It does not have to be abandoned as new research findings and new data become available. Rather it can be readily modified and updated to incorporate new information. Indeed it is only as good as the data upon which it is based and must be revised if it is to remain a useful tool in the arsenal to combat acid deposition.

This last point has implications for the future application of the Screening Model. Our ability to comprehend the overall environmental system may diminish as the information available to us increases and becomes more complex. The Screening Model can help in this regard since the model structure can be adapted to accommodate new types of information. Two very pertinent examples of such information are receptor damages and transfer coefficient data for other acidic pollutants such as NO_x. Once estimates of receptor damages have been established for all of the significant receptor areas, then these can be entered directly into the economic calculations of the Screening Model. Emission control costs could then be traded off directly against receptor damages in order to determine acceptable deposition targets.

Apart from its role in the analysis of management strategies, the Screening Model may be able to provide some assistance in prioritizing acid deposition research efforts. Much of the information on acid deposition that is currently available is subject to varying degrees of uncertainty. Using sensitive analysis, the significance of these various sources of uncertainty to decisions regarding abatement can be assessed with the Screening Model. Research efforts can be directed to those areas where uncertainty appears to be most critical.

Finally, it is conceivable that in a revised form, with significantly improved input data, the

Screening Model could be used during the implementation phase of an acid deposition abatement program. It could provide one means of assessing, for example, the economic implications of various degrees of control at important new sources or of evaluating economic penalties for non-compliance on the part of polluters.

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